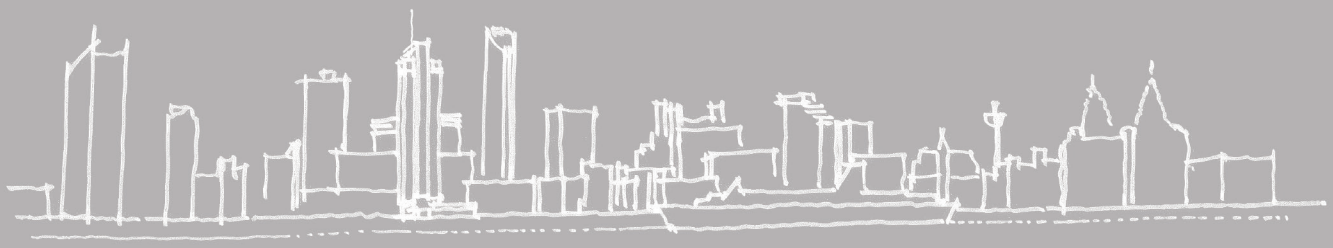
MODALIVING

A DESIGN FOR LIFE

PRINCES REACH, PRINCES DOCK

PHASE 1 GROUND CONDITIONS AND GEOTECHNICAL REPORT

June 2016



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1 Introduction

1.1 The Brief

Ove Arup and Partners (Arup) have been commissioned by Moda Living to undertake a geotechnical and geo-environmental desk study for the proposed development of 'Princes Reach, Liverpool'.

This report presents the findings of the geotechnical and geo-environmental desk study which aims to:

- Understand the site specific ground conditions;
- Identify any geological, geotechnical, geo-environmental or hydrological constraints of the site;
- Locate and provide details of any surface, sub-surface structures or utilities that have the potential to affect or be affected by the development; and
- Inform the design and planning of future ground investigation works.

1.2 Parties Involved

The following parties are currently involved in the delivery of this project:

- Moda Living who are the Client;
- Falconer Chester Hall who are the Architect;
- Ridge who are the Project Managers;
- PdF Heritage and SJF Archaeology who are Archaeological Consultants;
- Ove Arup and Partners who are providing multidisciplinary design services;
- Arcadis who are the Quantity Surveyors;
- Mott MacDonald who are the Transport Consultants; and
- Planit-ie who are the Landscape Architects.

1.3 Report Structure

This report provides a review of available documentary records from a variety of sources in order to inform the Princes Reach development. The structure of the report is as follows:

- Section 1 introduces the project and defines the aims and limitations;
- Section 2 describes the site setting and local area;
- Section 3 describes the site history and the archaeological and heritage potential;
- Section 4 describes the below ground constraints within the site boundary;

- Section 5 describes the ground conditions, including publically available information, archive information obtained from Liverpool City Council, and Arup archives;
- Section 6 describes archive information obtained from Arup archives;
- Section 7 discusses publically available hydrological and hydrogeological information;
- Section 8 assesses the potential for ground contamination on the site and its possible impact;
- Section 9 assesses identified engineering considerations;
- Section 10 presents a geotechnical and geo-environmental risk register; and
- Section 11 summarises the ground-related conditions and recommendations for further work.

1.4 Sources of Information

The findings of this desk study report are based upon available information from publically available sources as well relevant project data from Arup archives and Groundsure. A separate record search was undertaken with Liverpool City Council.

The following sources have been reviewed:

- Publically available data from the British Geological Survey (BGS) and Environment Agency (EA);
- Groundsure Geoinsight Report, Groundsure Enviroinsight Report, and Historical Mapping;
- Groundsure Preliminary UXO Risk Assessment Report;
- Arup Archives – Malmaison Hotel Development 2002;
- Arup Archives – Princes Dock Infrastructure 1998;
- Arup Archives – Princes Dock Infrastructure 1995;
- Historical mapping; and
- Liverpool City Council Environmental Protection Unit contaminated land search information.

A request for Mersey Docks and Harbour Company (MDHC) records has been made but as yet no information has been received. Further desk study sources may also come to light during the design process and the impact of these should be considered and this desk study updated accordingly.

1.5 Limitations

This study has been prepared by Ove Arup and Partners Ltd on behalf of their Client, Moda Living, and takes into account their particular instructions and

requirements. It is not intended for, and should not be relied upon by any third party and no responsibility or warranty is undertaken by any third party.

2 The Site

2.1 Site Location and Boundaries

The site is located at National Grid Reference **SJ336908** and its location is shown on Figure 1.

The site is bounded by hardstanding car park to the north, a high brick boundary wall to the east, hardstanding car parking to the south and a road (William Jessop Way) to the west.

2.2 Topography

The topography of the site is generally relatively flat with existing levels for the main portion (hardstanding) of the site between 7.59mOD and 7.05mOD. To the west, there is a grass embankment between the hardstanding car park and the road William Jessop way. Here, the ground slopes in a westerly direction to William Jessop Way, from approximately 7.59mOD to 6.65mOD, an approximate gradient of 1 in 5. A topographical survey has been completed for the site [1].

2.3 Present Use

The site is currently hardstanding comprising cobbles and tarmac, and is currently derelict although it has previously been used as car parking. A plan of the site is presented in Figure 2 and an aerial photograph showing the site is presented in Figure 3.

2.4 Listed Buildings and Heritage Assets

There are a number of features within the site which are listed or are of archaeological and heritage value. The main feature of relevance in this context is the free-standing masonry wall along the eastern site boundary with Bath Street. This wall and associated gates, are Grade II Listed and form part of the UNESCO World Heritage Site Character Area. As discussed below, there are other historic features within the site that are also considered to have heritage value.

2.5 Proposed Development

At the time of writing, design proposals are at an early stage. The following information has been taken from the Planning Pre-Application document [1].

It is proposed that the development will be a landmark tower building, circa 34 storeys in height. The proposed development will be predominantly residential space. The ground floor will be car parking, a leisure unit and general facilities such as substation and plant rooms. A core containing lifts and stairwell is proposed. The first floor also comprises car parking space to the south, and residential flats to the northern side of the building. The second floor upwards is predominantly residential, with some levels of car parking and communal terrace space. It is understood that a basement structure is not proposed. At the time of writing, landscaping requirements are not known.

At this stage in design a foundation strategy has not been confirmed, however it is envisaged that a bored pile solution will be proposed, with toe levels within competent rock.

2.6 Site Walkover

In December 2015 a site walkover was carried out. The site is open and publically accessible and therefore there were no access restrictions. The site was accessed via an existing opening in the boundary wall along Bath Street and from an access path from William Jessop Way.

At the time, the site was open space and not in use. The western side of the site was found to be hardstanding/tarmac in the south and centre and un-bound gravel surface in the north. The eastern side of the site, nearest the boundary wall was found to be surfaced with cobbles/setts, with a number of associated rail tracks. It is possible that the change in surface indicates the approximate location of the historical dock wall (discussed further in Section 3.4) with original surfacing to the east and the western side being laid more recently following the reclamation and infill of Princes Dock.

Two street lights were identified approximately 2m west of the eastern boundary wall. It was not clear whether these were in use.

Photographs from the site walkover are presented in Appendix A, along with a plan showing the approximate location and direction the photos were taken.

3 Site History

3.1 Sources of Information

- A Magnificent Monument of Mural Art – The Story of Princes Dock, Adrian Jarvis, 1991 [4];
- Groundsure historical mapping (Appendix D);
- Historical maps obtained from Mersey Docks and Harbour Company;
- Information obtained from Liverpool City Council Environmental Protection Unit (Appendix E); and
- Discussions with Arup staff who have past experience of working on projects in the area.

3.2 Summary of Site History

A plan of Liverpool from 1785 shows the site straddled the banks of the River Mersey, with the river wall running generally north-south through the site.

The construction of Princes Dock started in 1811 and was formally opened on 19th July 1821. The free-standing wall that currently forms the eastern site boundary wall was constructed in July 1813 to ensure the security of the dock.

An extract from an 1830 plan shows that by this time the area had undergone extensive redevelopment. Princes Dock is shown with the eastern dock wall fairly linear but with evidence of two 'L shaped' features just inland, that appear to be either a historical river wall or a previous dock wall. The present day Bath Street is present.

Between 1850 and 1893, significant changes are recorded with sheds present extending from the dock wall to midway back towards the boundary wall. These were open sheds with cast iron columns supporting wooden trusses and a planked and slated roof. The 1893 plan shows an overhead railway line had been constructed between the shed and the boundary wall. By 1908 additional railway tracks have been added between the sheds and the boundary wall; it is assumed that these were at grade rather than elevated.

In 1928 to 1929 reinforced concrete stagings were constructed over the full length of the eastern dock area together with new sheds along the dock side. A photograph of the staging has been obtained from Arup archives that was taken in 1998 during infrastructure works. This photograph shows the staging and the supporting reinforced concrete stanchions (**Photo 2.1**)

During the Second World War, approximately 2,500 bombs were dropped on Liverpool, however no bomb damage has been recorded directly on the site. Further information with regards to the risk of unexploded ordnance (UXO) is discussed in Section 3.3.

Plans from 1953 to 1954 show a reduction in railway lines which corresponds to the closure and removal of the overhead railway. Some railway lines remain marked on plans until 1982-1984. By 1993 the sheds have been demolished and since this time the site has mainly operated as a surface car park.

In the mid 1990's the site was the subject of reclamation works and redevelopment. As part of this work, the concrete staging was demolished. The supporting stanchions were left in place although reduced in height. **Photo 2.2** and **Photo 2.3** show evidence of the removal of the staging, as the dock wall can be seen to be exposed. Part of the dock was subsequently backfilled and a new anchored sheet pile retaining wall was constructed to retain a new access road (William Jessop Way). The infill is known to be general construction waste, although perhaps sorted to some degree as shown in **Photo 2.6**. The fill beneath the road was improved by vibrocompaction techniques. At this stage, the site was now completely on land, with the original dock wall approximately central to the site.

A summary of the significant site features observed on the historical maps is presented in Table 1 below. Selected maps are presented as Figure 4 to Figure 10.

Table 1: A summary of the site history based on historical maps

Map	Significant site features
1785	The site is predominantly offshore within the River Mersey. No evidence of Princes Dock. (Figure 4). A Fort is indicated to the north of the site, and Baths to the south.
Horwood 1803	A change in the shape of the dock wall is indicated (Figure 5). This is also evident in the 1832 William Hartley map.
1850 Scale:1:10.560	The original Princes Dock Wall is in approximately the middle of the site, with the western part of the site within the dock and the eastern side on land. Princes Dock is present, with a relatively straight boundary wall along the eastern boundary. Sheds are present from the edge of the dock to mid-way back towards the Bath Street boundary wall. Baths and Fort are no longer present. (Figure 6).
1893 Scale 1:2.500	Railway lines are present between the East Sheds and boundary wall. (Figure 7).
1908 Scale 1:2,500	Extension of railway lines that cover the eastern portion of the site between the East Sheds and boundary wall. Mooring posts along the length of the dock wall. (Figure 8).
1927 Scale 1:2,500	No Change. Evidence of development within close proximity to the site.
1953 to 1954 Scale 1:2,500	Construction of staging along the eastern dock wall. Some reduction in railway lines. (Figure 9).
1968 to 1969 Scale 1:1,250	No Change.

1975 to 1978 Scale 1:1,250	No Change.
1982 to 1984 Scale 1:1,250	Railway lines no longer marked.
1993 Scale 1:1,250	Sheds no longer present. (Figure 10)
2002 Scale 1:10,000	Evidence of redevelopment, change in the shape of the dock

3.3 Unexploded Ordnance (UXO)

CIRIA Report C681 "Unexploded ordnance – a guide for the construction industry" sets out a framework for the management of risks posed by UXO to the construction industry. The framework for the risk management process is divided into four distinct stages:

- Preliminary risk assessment
- Detailed risk assessment
- Risk mitigation
- Implementation

This is intended to ensure that the potential risk from UXO is addressed in an efficient and cost effective way.

During WWII, around 2,500 bombs were dropped on Liverpool, leading to considerable damage across the city. No complete bomb census mapping for Liverpool has survived.

A preliminary Unexploded Ordnance Risk Assessment [3] was obtained from BACTEC and recommended that a full Explosive Ordnance Desktop Study was undertaken for the site.

A more detailed Explosive Ordnance Desktop Threat Assessment was subsequently undertaken by Dynasafe BACTEC [16] and is included in Appendix C. This report concluded that there was a medium to high risk of UXO at the site. It was recommended that UXO risk mitigation measures were implemented for any proposed works, including Explosive Ordnance Safety and Awareness briefings to site personnel, and the provision of an Explosive Ordnance Disposal Engineer on site to support intrusive works.

3.4 Archaeology

Several heritage features have been identified on the site, and an Archaeological Consultant has been appointed as part of the project (as discussed in Section 1.2). Their specialist advice is to be sought and considered separately at every stage of the project.

The Archaeological Deposit Model has been reviewed and is presented in Figure 11. This model assists in identifying areas of high, medium and low archaeological potential by consolidating historical map data and baseline information (such as aerial photographs) on heritage assets to identify structures. For this site, these are associated with the historical docks. The site lies within areas currently identified as high and medium archaeological potential. Two distinct areas of high archaeological potential can be easily identified from Figure 11, both walls, one linear and in continuum with the historical footprint of the dock – the historical dock wall, and one appearing as a "handle" shape just to the landward (eastern) side of the dock – possibly the historical river wall.

As further archaeological investigations take place as part of this project, the model should be updated accordingly.

From discussions with the Archaeological Consultant, it is understood that surface heritage assets, such as cobbles/setts, historical rail and former tram shed footings, should be retained and/or investigated archaeologically. Disturbance of such features should be avoided prior to gaining the advice of an Archaeological Consultant, such that their existing condition and locations may be recorded and surface assets potentially reinstated. An Archaeological Watching Brief will be required during all intrusive works at the site.

The heritage assets that have been identified at this stage of the project are:

- Historical river wall, identified as the 'handle' shape eastwards of the dock wall;
- Historical dock wall, running north to south through the site;
- The free-standing boundary wall between the site and Bath Street; and
- Surface features such as cobbles/setts, historical rail, tram shed footings.

The below ground features are discussed in further detail in Section 4 below.

4 Below Ground Constraints

The following section summarises the below ground physical constraints that have been identified during the review of historic documents undertaken as part of this study. Figure 12 presents a visual summary of the findings.

4.1 River Wall and Dock Wall

Two slightly different alignments of the river wall were indicated on pre-Ordnance Survey maps, shown in light blue and green on Figure 12. These alignments are indicative only, given the age of the source maps. It is possible that the masonry of the river wall may have been robbed out to some extent during the construction of Princes Dock.

The more recent dock wall has been identified as being present running north to south, almost central to the site. Historical ground investigations near the site have investigated it and further details can be found in Section 6.1.6.

The river wall and dock wall have been identified as potential archaeological assets and therefore specialist guidance and approvals will be needed prior to any intrusive works being undertaken in their vicinity.

4.2 Ground Anchors

The sheet pile wall that supports William Jessop Way is anchored back via a series of steel tie rods and anchor plates, comprising shorter sections of sheet piling. The anchor capacity is generated by the soil in front of the anchor plate. Therefore these only form a constraint if excavation is proposed on the dock side of the anchor plates. However, disturbance of these plates and excavation behind and close to the edge of the plates should be avoided.

Details of the design and construction of the sheet pile wall and anchor arrangement are available in the Arup archive information.

4.3 Concrete Stanchions

Reinforced concrete staging was added to the dock in 1928 to 1929 to provide additional space alongside the dock wall for warehouses and storage. The staging was supported by concrete stanchions typically at 3.75m spacing (east-west spacing) with associated cross bracing. Within each row, the concrete stanchions were typically at 4.2m centres (north-south spacing). It is understood that the site is underlain by four rows of concrete stanchions, as shown in grey in Figure 12. Historical photographs show the staging and these are included in Appendix 2 (**Photo 3.1** and **Photo 3.2**).

It is understood from discussions with Arup staff that the bracing was removed as part of the dock reclamation and the columns were broken down. Photographs found in the Arup archives confirm this (**Photo 2.2**, **Photo 2.3**). Information found within the archives for a nearby project (see Section 6.1) has confirmed the

understanding that the columns were broken down to an elevation of 4.8mOD, approximately 2.6m below existing ground level.

4.4 Services

A Groundwise Utilities survey has been carried out and the report is available. The implications of the existing utilities will be reported separately.

5 Ground Conditions

5.1 Regional Geology

The British Geological Survey (BGS) online Geo-Index (1:50,000 scale mapping) [5] indicates that the bedrock geology is the Sherwood Sandstone Group – Chester Pebble Beds formation. The BGS Lexicon of named rock units [6] describes this stratum as fine to coarse grained sandstone, cross stratified, commonly found with pebbles and sporadic conglomerates and siltstones. It is generally found to be between 90m and 220m in thickness. The geological map is presented in Figure 13.

The superficial deposits are indicated to be Tidal Flat deposits, consolidated soft silty clays with layers of sand, gravel and peat. These are tidal deposits associated with the tidal zone of the River Mersey that the site was once part of. From historical ground investigations nearby to the site, it is understood that these naturally occurring deposits are unlikely to be found beneath the site as a result of historical developments. This is discussed in Section 5.3.

5.2 BGS Historical Boreholes

The British Geological Survey (BGS) provides access to a number of historical borehole scans across the UK. A search has been carried out to access those close to the site, and all within the area of interest are noted as confidential and therefore not publically accessible.

5.3 Historical Ground Investigations

The site has been extensively redeveloped in recent history, as discussed in Section 3. As part of this desk study, information from Arup's archives have been reviewed and is presented in Section 6 below. This presents data relevant to the ground conditions that have been obtained from the archive search for projects on, or close by to the site. The location of the historical boreholes that have been considered relevant to this review are presented Figure 14.

6 Information from Arup Archives

6.1 Ian Farmer Associates 2002 – Malmaison Hotel Development

The Malmaison Hotel was the development of a nine storey hotel on the east side of Princes Dock, approximately 300m south-west of the site of the current development site.

The Malmaison Hotel, Liverpool, Geotechnical Report (May 2002) prepared by Ove Arup and Partners has been reviewed [7].

In December 2001, and March 2002, Ian Farmer Associates (IFA) under the supervision of Arup carried out a ground investigation that comprised four light cable percussion boreholes to 5m below rockhead to a maximum depth of 18m, two hand dug pits to a maximum depth of 1.3m, and two machine dug trial pits to a maximum depth of 4.5m.

Following the completion of the boreholes, a gas monitoring standpipe was installed in one borehole and three further standpipes either side of the dock wall. These enabled water levels to be monitored. Soil, rock and groundwater samples were taken from boreholes and trial pits and were sent for geotechnical and contamination testing.

For the purposes of reporting ground conditions, the site was divided into two areas, separated by the Dock Wall; Area A to the east of the wall (landside), and Area B to the west of the wall (dockside). Using Figure 5 of the Arup report, a cross section of the site has been developed and is presented in in Figure 15.

It can be seen from Figure 15 that Made Ground is present to the eastern side of the dock wall to between 4.25m and 7.5m below ground level. This is underlain by ‘Bunter Sandstone’ (renamed by the BGS as the ‘Sherwood Sandstone Group’). Rockhead dips towards the dock wall (westerly) at an approximate angle of 22˚ from +2.75mOD in the east to -0.5mOD (probable depth) beneath the dock wall. To the western side of the dock wall (Area B) there are four different types of fill overlying the Bunter Sandstone. Between the ‘New Road’ (now William Jessop Way) there is approximately 0.7m of engineered fill, understood to comprise sub-base, overlying uncontrolled fill and silt deposits. It appears that there in some uncertainty in terms of the depth to rockhead. It is understood that vibro-compaction ground treatment was undertaken beneath the new highway but that this ground treatment does not extend to the development plots.

The stratigraphy encountered as reported in the Malmaison Geotechnical Report is presented in Table 2 below.

Table 2: General stratigraphy reported in Malmaison Geotechnical Report (May 2002)

Stratum	Area A thickness (m)	Area B thickness (m)
Made Ground	4.15 – 6.00	Not Present
Recently Placed Fill	Not Present	6.70m
Dock Silt	Not Present	4.70 – 5.00
Sandstone Bedrock	>6.35	>6.30

6.1.1 Made Ground

The Made Ground in Area A generally comprised an upper layer of loose to medium dense brown and orange brown gravelly sand. With depth it graded into a soft brown sandy clay.

The Made Ground in Area B was placed in 1999 as part of the dock reclamation scheme. It is understood from Arup experience that this material was end tipped and is generally loose brown, gravelly sand containing some demolition debris, some places in large concrete blocks up to 1m³ in size.

A summary of the geotechnical parameters of the Made Ground is in Section 6.1.3.1 below.

6.1.2 Dock Silt

Encountered in Area B, the dock silt was encountered as a soft brown/black, locally peaty, slightly sandy silt.

A summary of the geotechnical parameters of the Made Ground is in Section 6.1.3.1 below.

6.1.3 Sandstone Bedrock

Boreholes 1, 2 and 4 encountered a thin layer of weathered sandstone on top of the bedrock. This weathered layer was generally described as a very dense, red brown, slightly silty, gravelly, fine to coarse sand/sandy gravel of weak sandstone. It is noted that chiselling at the base of the boreholes may have contributed to this layer.

The underlying bedrock was generally found to be moderately weak to moderately strong brown and red brown medium grained sandstone with horizontal to sub-horizontal bedding. Occasional sub vertical clay filled joints were observed. The laboratory testing indicated a slightly higher strength than the visual description although this could be as a result of the sampling methods, where typically stronger layers are tested. Laboratory test results indicate the sandstone to be moderately strong although grading to moderately weak at the surface. No trend of an increase in strength with depth was observed.

A summary of the geotechnical parameters of the Made Ground is in Section 6.1.3.1 below.

6.1.3.1 Geotechnical Parameters

Table 3: Summary of Geotechnical Parameters from the Malmaison Hotel site investigation 2002.

Stratum	**SPT N Value**		**Plasticity Index**	**Moisture Content (%)**	**Consolidation Values (m^2/MN)**	**Undrained Shear Strength Cu (kPa)**	**Organic Content (%)**	**pH**	**Sulphate g/l**	**Point Load $I_{s(50)}$ (MN/m^2)**	**Uniaxial Compressive Strength UCS (MN/m^2)**
	Area A	Area B	Area B	Area B	Area B	Area B	Area B	Area B	Area B	Site wide	Site wide
Made Ground	11 to 22	2 to 20*									
Dock Silt			60 to 92	111 to 147	4.4 to 1.3 with depth	5 to 15 with depth	6.9 to 13.1	7.4 to 7.7	0.17 to 0.23	-	-
Sandstone Bedrock	-	-	-	-	-	-	-	-	-	0.32 to 2.15	11.3 to 27

*higher recorded values considered unrepresentative.

6.1.4 Groundwater

Groundwater was not encountered in Area A to the eastern side of the dock wall and subsequent monitoring in the Made Ground indicated it to be dry.

It appears that the presence of the original dock wall results in the groundwater levels in Area A being substantially lower in comparison to Area B where the groundwater level corresponds to the water level in the dock.

Table 4: Water monitoring from the Malmaison GI (2002)

Borehole	Water Level (mbgl)					
	03/01/2002	29/01/2002	21/03/2002	22/03/2002	28/03/2002	03/04/2002
BH1	-	-	dry	-	dry	4.47
BH3	4.34	4.35	-	4.27	4.31	4.34

6.1.5 Contamination

Chemical testing was undertaken on 18 soil samples for metals, cyanide, sulphide, sulphate, pH, phenols, polycyclic aromatic hydrocarbons (PAH), total petroleum hydrocarbons (TPH), mineral oils and polychlorinated biphenyls (PCBs). The assessment did not identify any widespread contamination that was considered to be a risk to human health however concentrations of copper, zinc and boron were reported to pose a phytotoxic risk to plants.

One groundwater sample was tested for metals, sulphate, PAH, mineral oil, chloride and BTEX. No significantly elevated concentrations of contaminants were reported in groundwater.

Ground gas monitoring was undertaken on several occasions over a three month period. Elevated concentrations of methane up to 8.6% were reported and gas flow rates were up to 1.2 l/h. The gas risk assessment indicated that gas protection measures would be required in new buildings.

It should be noted that the ground investigation data is over 13 years old and therefore may be unreliable due to changes in logging testing and risk assessment guidelines.

6.1.6 Dock Wall

Two trial pits were carried out as part of the 2002 site investigation to investigate the location and geometry of the dock wall. The trial pits encountered the top of the dock wall at a depth of 1.40m and confirmed the wall width to be 1.90m.

The front face of the dock wall was found to slope at a gradient of 1 in 12.5 to a depth of 2.50m below the top of the wall. Original construction drawings of the wall that were found as part of this project show a gradient of 1 in 9 to a depth of 6.70m where a step of 0.20m is seen. A further step is seen at a depth of 9.68m where the wall gradient increases to 1 in 3.3. The drawing indicates a wall height of 11m.

The trial pits indicate the back of the wall to be vertical to a depth of 4m however earlier investigations suggest it is founded at an elevation of -0.5mOD (some 4m lower). It is possible that the wall widens towards the base.

The geometry of the dock wall shown in Figure 15 is based on photographs from [4] and was considered the most likely construction.

6.1.7 Boundary Wall

Trial pits were excavated to determine the founding details of the boundary wall and these were proved to a depth of 1.10m below pavement level, stepping out from the wall line by up to 0.55m. One pit was excavated next to a cast iron column associated with the former overhead railway and it was found that the railway was founded on concrete pads sitting directly on the wall foundations.

6.1.8 Concrete Staging

The Malmaison ground investigation did not encounter evidence of concrete staging that may remain in place. The report provides evidence from discussions with Arup staff that the bracing was removed during the dock reclamation and the stanchions were broken down to an elevation of 4.8mOD, 2.6m below existing level. This is in agreement with photographs obtained from earlier archives, as shown in **Photo 2.2** and **Photo 2.3**.

6.1.9 Below Ground Obstructions

The site investigation revealed the presence of many obstructions in the fill up to depths of around 6m and it was recommended that excavation of pile positions would be required prior to piling. It is not known whether obstructions were an issue during piling.

6.2 Foundation and Exploration Associates 1998 – Princes Dock Infrastructure

The Princes Dock Infrastructure development included the construction of a new sheet pile wall and construction of a new highway as well as the provision of new services. Arup were appointed by Princes Dock Development Company as the Consulting Engineers. Between April and June 1998, and November and December 1998 Foundation and Exploration Associates carried out a ground investigation under the supervision of Arup.

The factual report produced by Foundation and Exploration Associates [8], [9] has been reviewed, alongside the Interim Geotechnical Report [10] and the following section presents the relevant information. The site investigation was undertaken in three phases and the relevant exploratory holes from these have been considered as follows:

Table 5: Relevant Exploratory holes from the 1998 Foundation Exploration Associates GI

Phase	Exploratory hole
1	TP106, TP107, TP111
2	BH201/A, BH202, BH203, BH205, BH206
3	No relevant data

Phase 1 was completed at the time Princes Dock was in the process of being reclaimed by infilling. Phase 2 was completed following the completion of the filling operation.

Table 6: General Stratigraphy inferred from relevant boreholes from the Princes Dock Infrastructure Investigation 1998

Stratum	Approximate thickness (m)	Approximate elevation of top (mOD)
Made Ground	6.10 to 12.10	Ground Level
Dock Silt	1.0	-3.03
Sandstone Bedrock	>0.6	-4.03 to -4.93

6.2.1 Made Ground

The Made Ground encountered in the relevant exploratory holes was generally described as light brown subangular fine to coarse gravel including brick and limestone with some fine to coarse sand and a little to some silt. Occasional fragments of tarmac, metal and ceramic were encountered. Some laboratory testing was carried out on samples of the made ground and these are summarised in Table 7.

6.2.2 Silt

Silt was encountered in one borehole (BH201A) which is located south of the site. The silt is described as very soft and black in colour, with a little fine and medium sand. It is noted to possibly be Made Ground.

6.2.3 Sandstone Bedrock

Generally the sandstone encountered was described as red-brown highly weathered, fine and medium grained sandstone, moderately weak. All boreholes were terminated after a short penetration depth into the sandstone and therefore less weathered material was not proven.

6.2.4 Groundwater

No groundwater monitoring was carried out in the relevant boreholes.

6.2.5 Below Ground obstructions

Photographs taken around the time of this investigation show the infill material to be general construction fill. It appears that some attempt may have been made to sort the material. However in the absence of records of this work it should be assumed that obstructions may be found **Photo 2.6**.

6.2.6 Geotechnical Parameters

The following table summarises the geotechnical parameters as a result of laboratory tests carried out on samples from relevant exploratory holes.

Table 7: Summary of geotechnical properties from laboratory testing from relevant boreholes

Stratum	Plasticity Index	Moisture Content (%)	Bulk Density (Mg/m^3)	SPT N Value	pH	Sulphate SO4 (% of dry mass)	Sulphate SO4 groundwater (g/l)	Chloride Content as Cl (% of dry mass)	California Bearing Ratio CBR (%)
Made Ground	24 to 42	15 to 143	1.42	3 to 26	7 to 10.5	0.05 to 0.16	1.19 to 1.88	0.09 to 0.13	1.8

6.3 Exploration Associates 1995 – Princes Dock, Liverpool

As part of a proposal for the development of Princes Dock, Liverpool, in 1995, Exploration Associates (EA) carried out a ground investigation, supervised by Arup.

The investigation was carried out between 23rd January and 22nd February 1995 and comprised twenty four boreholes excavated using cable percussion and rotary coring techniques, and twenty two trial pits excavated by both machine and by hand.

The works were carried out across the full extent of the dock, and therefore only certain exploratory holes have been considered relevant to this site. The exploratory holes considered are BH11(A) and TP21(A).

A ground probing radar survey was also carried out to investigate the existence of possible subsurface voiding. Due to the poor quality of the archive scans available, it has not been possible to interpret this data.

The stratigraphy encountered as reported in Factual Report on Ground Investigation [11] is presented in Table 8 below.

Table 8: General stratigraphy from relevant borehole records from the 1995 EA ground investigation.

Stratum	Approximate thickness (m)	Approximate top elevation (mOD)
Made Ground	5.80	1.36
Sandstone Bedrock	>1.2m	0.16

6.3.1 Made Ground

The Made Ground encountered within the two exploratory holes that are relevant to this site is generally described as a loose red and brown sandy clay fill with fragments of brick, concrete and sandstone.

Two in-situ Standard Penetration Tests (SPTs) were carried out within the Made Ground, indicating SPT N values of 18 between 1.00 and 1.45m depth, and 12 between 2.60 and 3.05m depth.

Index testing that was carried out in BH11 from samples within the Made Ground indicate a water content of 17 to 21% and a plasticity index of 47 to 64%. An undisturbed, undrained multistage triaxial test was carried out on one sample, indicating an undrained shear strength of 17kPa.

One sample of Made Ground was subject to chemical testing, indicating a slightly alkaline pH of 8.76.

6.3.2 Sandstone Bedrock

The sandstone bedrock encountered in the two exploratory holes relevant to this site is generally described as yellow brown weathered sandstone. BH11 was terminated 1.2m into the sandstone and did not prove less weathered material.

Two in-situ SPT tests were carried out within the weathered sandstone, both refusing at more than 50 blows for 75mm penetration.

6.3.3 Groundwater

Standpipe piezometers were installed within the boreholes, including BH11 and this is presented in the interpretive report for this investigation [12]. During February 1995 the dock water levels were monitored and to the eastern side of the dock, monitoring over a full tidal cycle indicated that no significant tidal influence was observed. Groundwater levels recorded equated approximately to the dock water level. Tidal influences were observed to the western side of the dock.

In general, to the eastern side of the dock, groundwater levels were observed to be between approximately 2.5m to 3.9m below ground level.

The piezometer installed in BH11 with a tip depth of 6.30m, recorded water levels between 2.20 and 2.78m below ground level.

The trial pit record for TP21A records water ingress at 3.40m depth.

6.3.4 Dock Wall

Trial Pit TP21A exposed the sandstone masonry of the backfilled and existing dock walls. From a section provided in the factual report it appears that the dock wall is comprised of sandstone blocks and is approximately 2.0m in cross sectional thickness at the top. The sketch does not provide further detail with regards to geometry.

To the eastern (landside) of this dock wall, another sandstone masonry wall has been recorded. No further geometry with regards to this wall is provided, it is possible that this is the original dock wall that has been discussed in Section 4.1.

The factual report noted that a number of potential voids and hard and soft spots were indicated by the radar survey. It should be noted that this investigation was carried out prior to works infilling the docks and associated infrastructure works.

7 Groundwater

7.1 Hydrology

Princes Dock is approximately 16m west of the site boundary. A sheet pile wall forms the current dock boundary.

The River Mersey is at the western side of Princes Dock, approximately 140m west of the site.

7.2 Hydrogeology

The Groundsure report [13] indicates that the Environment Agency has classified the superficial deposits as ‘unproductive’. This means they are low permeability and have negligible significance to water supply or base flow. From the archive information obtained, it is thought unlikely that the natural superficial deposits remain on site and that Made Ground is present. It is likely that the Made Ground has the potential to hold groundwater at a local scale, likely to be influenced by the water level of the dock.

The Environment Agency [14] has designated the bedrock geology as a principal aquifer, where the deposit has a high permeability and therefore a high level of water storage that can support water supply or river base flow on a strategic scale. The site has high groundwater vulnerability.

No groundwater abstraction licenses have been identified on the site, however three have been identified within a 500mm search radius of the site.

The site is not within a groundwater protection zone.

8 Contaminated Land - Preliminary Conceptual Site Model

8.1 Introduction

A preliminary conceptual site model has been prepared based on available desk study information to inform the design of the ground investigation.

A conceptual model describes the scenario in which the risks to human health and the environment posed by contaminated land are assessed. It describes the ground and surface conditions, and the activities performed on site in terms of the proposed ground works and the final form of the development. In particular the model identifies and describes the sources of the potential contamination, the behaviour of the contamination in the environmental media such as soil and groundwater, surface water and air. It also identifies and characterises potential human health and environmental receptors, and plausible pathways.

The potential risks to human health and the environment have been considered in the context of a conceptual source-pathway-receptor (SPR) model of the site, identifying:

- The principal pollutant hazards associated with the site (the **sources**);
- The principal **receptors** at risk from the identified hazards; and
- The existence, or absence, of plausible **pathways** which may exist between the identified hazards and receptor.

For risks to be present at the site, all three elements (source-pathway-receptor) of a plausible pollutant linkage must be present. Potential SPR linkages are described below based on the proposed site end-uses.

8.2 Potential Sources

Potential sources of contamination may be present associated with historical land uses. A summary of the potential contaminants that could be associated with the historical uses of the site is provided in Table 9. The potential contaminants have been identified, where possible, from the Department of Environment 'Industry Profiles' publications [15].

Table 9: Potential Sources of Contamination

Potential Source	Potentially Contaminative Materials	Comments
Made ground associated with dock construction/infill	Asbestos Heavy metals Hydrocarbons (including petroleum hydrocarbons, phenols, Polyaromatic hydrocarbons (PAHs)) Inorganics (e.g. sulphate, sulphide, chloride, cyanide, ammonia/nitrate)	Source of fill used in original dock construction unknown but is likely to have included waste materials from the local area (e.g. industrial waste, building rubble, marine dredgings). Fill used in reclamation work in mid 1990s known to be general construction waste.

	Ground gases (methane, carbon dioxide, carbon monoxide, hydrogen sulphide, volatile organic compounds (VOCs)	Potential for generation of ground gas will depend on the organic content of the material
Historical dock activities including cargo storage, handling plant and equipment, ship repair/maintenance	Asbestos Heavy metals Tributyltin Hydrocarbons (including petroleum hydrocarbons, phenols, Polyaromatic hydrocarbons (PAHs)) Solvents Polychlorinated biphenyls (PCBs) Inorganics (e.g. sulphate, sulphide, chloride, cyanide, ammonia/nitrate)	The contaminants will largely depend on the nature of cargo stored and the ancillary activities that were undertaken. Spillages/ onsite disposal Regulations historically less stringent
Railway	Heavy metals Asbestos Hydrocarbons (including petroleum hydrocarbons, phenols, Polyaromatic hydrocarbons (PAHs)) Ethylene glycol Creosote Sulphates	
Car parking	Heavy metals Hydrocarbons (including petroleum hydrocarbons, phenols, Polyaromatic hydrocarbons (PAHs)) Solvents	Site covered in hardstanding. Minor fuel leaks from parked cars unlikely to have caused widespread contamination.

8.3 Receptors

The following receptors have been identified at the site:

- Construction workers (during site construction/redevelopment);
- Users of neighbouring sites (during site construction/redevelopment);
- Future building resident/ building user;
- Future maintenance worker;
- Perched groundwater within Made Ground
- Bedrock groundwater (Principal aquifer);
- Surface Water (Princes Dock)
- River Mersey;
- Vegetation in soft landscaping areas
- Structural concrete; and
- Services and utilities.

8.4 Pathways

Potential pathways that may be present during redevelopment and operation include:

- Human health – Ingestion of soils or dust;
- Human health – Inhalation of dust, vapour or soil gas;
- Human health – Dermal contact with soils or groundwater;
- Controlled waters (predominantly) – Migration of dissolved phase contamination within groundwater;
- Controlled waters (and human health by vapours) – Transport of non-aqueous phase contaminants (such as petroleum hydrocarbons and solvents);
- Ground gas – Ingress of ground gas into buildings;
- Vegetation – Uptake via root system;
- Building structures and utilities – Direct contact with aggressive ground conditions.

8.5 Preliminary Assessment of Potential Pollutant Linkages

8.5.1 Human Health

During any excavations and earthworks required as part of the development, dermal, inhalation and ingestion pathways will be present to construction workers and site neighbours.

Post-development, ingestion, inhalation, dermal contact and tracked back dust pathways will only be present in areas of soft landscaping (soft landscaping proposals are still to be finalised).

Gas and vapour pathways will be present within the proposed new building.

8.5.2 Controlled Waters

The potential for pathways exists between possible contaminants in the Made Ground and shallow perched groundwater and Principal aquifer (via vertical and lateral migration of leachate).

Shallow groundwater is considered to be in hydraulic continuity with the Princes Dock and consequently a pathway exists between any contamination in groundwater and surface water within the dock and subsequently the River Mersey. Groundwater in the bedrock is also likely to provide baseflow to the River Mersey.

Leachate may be generated from stockpiles of excavated Made Ground during the construction process. If uncontrolled this leachate could flow along the ground surface and enter the Princes Dock which is in the vicinity of the site.

8.5.3 Ecological Receptors and Vegetation

Soft landscaping proposals have not been finalised. If soft landscaping is proposed then vegetation planted in these areas may be exposed to contaminants via uptake of these compounds by the plants root system.

8.5.4 Buried Structural Concrete and Utilities

Buried structures such as water supply pipes, building piles, foundations and basement walls and floor slab may come into direct contact with chemically aggressive ground which may reduce the integrity and design life of these structures.

8.6 Summary

A summary of the preliminary conceptual site model is presented in Table 10 below:

Table 10: Preliminary conceptual site model

Source		Pathway		Receptor	Comment/Possible Mitigation
Construction Phase					
Made Ground *(Asbestos, heavy metals and metalloids, hydrocarbons, solvents, PCBs, sulphate, sulphide, chloride, cyanide, ammonia/nitrate)*	→	Ingestion of soil and soil dust	→	Construction Worker	Mitigated using appropriate PPE and site briefings on risks associated with the contaminants of concern
		Dermal contact with soil and soil dust	→	Construction Worker	
		Inhalation of soil vapours	→	Construction Worker	
		Inhalation of soil dust	→	Construction Worker	Mitigated using appropriate PPE, site briefings and dust suppression
			→	User of neighbouring site	Mitigated using dust control measures and monitoring
Made Ground stockpiles *(Containing contaminants above)*	→	Leaching and run off along ground surface	→	Princes Dock	Mitigated with stockpile bunding and placement of stockpiles away from Princes Dock
Shallow Groundwater *(Containing contaminants above)*	→	Ingestion	→	Construction Worker	Mitigated using appropriate PPE and site briefings on risks associated with the contaminants of concern
		Dermal contact	→	Construction Worker	

Source		Pathway		Receptor	Comment/Possible Mitigation
Ground Gas from Made Ground *(Carbon dioxide, methane, carbon monoxide, hydrogen sulphide, VOC including light alkanes)*	→	Accumulation and inhalation of hazardous gases at asphyxiating/ toxic concentrations	→	Construction Worker (working in confined space)	Mitigated using gas monitoring alarms and following confined space working procedures (if necessary)
		Accumulation and ignition of hazardous gases at explosive concentrations	→	Construction Worker	Mitigated using monitoring alarms (if necessary)
Post Construction					
Soft landscaping (potentially site Made Ground) *Asbestos, heavy metals and metalloids, hydrocarbons, solvents, PCBs, sulphate, sulphide, chloride, cyanide, ammonia/nitrate)*	→	Ingestion of soil and soil dust	→	Future building resident/ user/ maintenance worker	Maintenance worker most likely to become exposed to soils in soft landscaping.
		Dermal contact with soil and soil dust	→	Future building resident/ user/ maintenance worker	
		Inhalation of soil dust	→	Future building resident/ user/ maintenance worker	
		Uptake via root system	→	Vegetation	
Made Ground *(Heavy metals and metalloids, hydrocarbons, solvents, PCBs, sulphate, sulphide, chloride, cyanide, ammonia/nitrate)*	→	Inhalation of soil vapours	→	Future building resident/ user/ maintenance worker	Volatile contaminants only
	→	Leaching and vertical migration	→	Groundwater	
	→	Direct contact	→	Buried concrete and services	
Shallow groundwater *(Containing dissolved contaminants listed above)*	→	Lateral flow of shallow groundwater	→	Princes Dock	
			→	River Mersey	
		Vertical flow of shallow groundwater	→	Sherwood Sandstone (Principal aquifer)	
		Preferential vertical flow along building piles	→	Sherwood Sandstone (Principal aquifer)	
		Direct contact	→	Building foundations	Shallow groundwater may be chemically aggressive to concrete

Source		Pathway		Receptor	Comment/Possible Mitigation
Ground Gas from Made Ground *(Carbon dioxide, methane, carbon monoxide, hydrogen sulphide, VOC including light alkanes)*	→	Accumulation and inhalation of hazardous gases at asphyxiating/ toxic concentrations	→	Future building resident/ user/ maintenance worker	
		Accumulation and ignition of hazardous gases at explosive concentrations	→	Future building resident/ user/ maintenance worker	
			→	Building	

9 Engineering Considerations

9.1 Made Ground – Variability and Obstructions

As part of the Princes Reach development, historic ground investigations was supplemented by an initial Stage of intrusive investigation, undertaken in March 2016 by Soil Engineering Limited. The objectives of the Stage1 investigation were limited and were aimed primarily at providing further information on the presence and location of buried historic features.

Ground investigation at the site has identified Made Ground as being highly variable, in many places containing general construction waste such as concrete, brick and metal, sometimes in large blocks. Such obstructions may present risks during site works, such as during excavation of exploratory holes during the ground investigation as well as subsequent piling works and excavations for substructures, utilities and drainage. Potential obstructions should be considered and all parties involved in the works should be made aware of their likely presence.

The adjacent highway, William Jessop Way, was treated by vibrocompaction as part of the infrastructure works; the adjacent development plots were not treated. As the ground was treated some time ago it is unlikely that residual settlement will occur, and if it does it is likely to be minor. However, it may be prudent to consider further ground treatment such as vibrocompaction prior to construction.

Two distinct areas of fill have been identified to the east and west of the buried dock wall. These fill types are of different ages and are likely to have different engineering properties and contamination risk. It will be necessary to fully characterise each fill type and the differing engineering properties will need to be considered during design as appropriate.

9.2 Depth to Rockhead

From archive information relating to nearby historical ground investigations, it appears likely that the depth to rockhead will vary as a result of the historic excavation of the dock basin. Historical ground investigation data suggests rockhead to be between 6m and 12m in depth and this variability should be considered during foundation design.

In addition, previous ground investigations have not proven the level and quality of the unweathered rock, which is essential for future pile design. Further GI work will aim to provide this information.

9.3 Groundwater

Groundwater monitoring as part of the 2002 Malmaison Hotel ground investigation indicates that groundwater levels between the old dock wall and the dock were found to be the same as in the adjacent dock (approx. between 2.3 and 4.5m below existing ground level).

Groundwater monitoring as part of the 1995 Princes Dock & Half Tide Dock Site Remediation & Infrastructure indicated that the groundwater levels at the eastern side of the dock have no significant tidal influences and were approximately consistent with the dock water level. Monitoring in a nearby borehole indicated a groundwater level of approximately 2.5 to 3.9m below ground level.

During the 2016 Stage 1 ground investigation, groundwater was encountered during trial pit excavations at approximately 3m below ground level.

Further ground investigation and monitoring will enable the site specific groundwater regime to be established.

Groundwater levels need to be taken into account for all excavations and should consider the potential for tidal or exceptional weather variations.

9.4 River Wall and Dock Wall

The 2016 Stage I ground investigation [17] exposed what are likely to be the robbed-out remains of the river wall at two locations within the site. It was not possible however, to establish the condition of the wall along its full alignment within the site. The extent to which this river wall remains in-situ is therefore, subject to some uncertainty and it is proposed that further information regarding the location and geometry of this wall will be obtained as part of further phases of ground investigation. The heritage value of the remains of the river wall should be determined by Archaeologists and their recommendations considered as part of the foundation strategy.

The original dock wall has been identified as being present running north to south, almost centrally through the site. This dock wall is an archaeological asset and therefore specialist guidance and approvals are needed prior to any construction works that may impact the wall. As discussed in more detail in Section 6.1.6, the dock wall has been identified during historic ground investigations and the location and geometry of the dock wall was also investigated as part of the 2016 Stage 1 ground investigation [17]. The presence of the dock wall must be considered as part of the foundation strategy and an appropriate exclusion zone should be implemented which considers both engineering and archaeological issues.

9.5 Boundary Wall

The boundary wall between the site and Bath Street is Grade 2 listed and has been identified as a heritage asset and therefore specialist guidance and approvals are needed prior to any works related to it. It is understood from archive information that footings associated with the wall extend into the site. These pose a potential obstruction to the proposed development. It is recommended that the location and geometry of the footings is investigated as part of the intrusive ground investigation and this work should be surveyed to an appropriate datum. The footings should be considered as part of the foundation strategy and an appropriate exclusion zone implemented.

9.6 Concrete Stanchions

From information obtained from archive data supplemented by the findings of the 2016 Stage 1 ground investigation, it has been established that the lower sections of concrete stanchions have been left in-situ. These stanchions pose a potential obstruction for piling and therefore potential clashes should be considered as part of the foundation design. It may be necessary to consider an extra allowance for relocating piles and redesign of pile caps in such locations.

9.7 Preliminary Foundation Strategy

Existing ground investigation information indicates a variable depth to rockhead of between 6 and 12m, with rockhead slightly deeper to the west of the former dock wall (where the sandstone level has been artificially lowered) and shallower to the east. Due to the high loading of the proposed development and the variable nature of the Made Ground, it is not considered that shallow/spread foundations will be appropriate for the development. The foundations to the building will need to be supported on piles.

The use of driven piles would not be suitable given the presence of obstructions in the Made Ground, the likely large magnitude of the loading and the penetration of rock required to achieve these loads.

At this stage of the development it is envisaged that conventionally bored cast in situ piles will be required, socketed up to 5m into the underlying unweathered bedrock. The pile diameters selected will be subject to vertical and lateral loading but are likely to be large (750 to 1200mm).

The presence of obstructions within the Made Ground would mean that the use of Continuous Flight Auger (CFA) techniques would probably not be suited to this site as the CFA technique affords very little means of overcoming buried obstructions compared to conventionally bored piles.

Given the likely high ground water levels and likely low stability of the Made Ground, the bored piles would need to be temporarily cased to rockhead.

The pile arisings will be saturated and unsuitable for reuse and allowance should be made for the cost of offsite disposal.

The piling solution will need to take due consideration of the need to mitigate disturbance of the below ground archaeology in the form of the historical walls. The Malmaison hotel archive pile layout plans indicate that a 6.5m pile exclusion zone was allowed for in the design, comprising a 1m zone on the city side (eastern) of the dock wall, an assumed 2m top of wall thickness and a 3.5m exclusion zone to the dockside (western) of the dock wall.

Following the proposed further phases of ground investigation, a suitable piling exclusion zone will need to be agreed for this scheme.

9.8 Ground Gas

The Made Ground soils beneath the site have the potential to generate ground gases which could pose an asphyxiation or explosive risk.

Further GI monitoring data is required to allow an appropriate ground gas risk assessment to be undertaken which should include consideration of potential tidal variation on the gas regime.

At this stage, allowances should be made for the incorporation of gas protection measures including specialist membrane with appropriate detailing around pile caps and other slab intrusions, as well as a sub-slab venting layer/void former.

9.9 Services

It is understood that existing services are present on the site, particularly to the eastern boundary close to William Jessop Way. A Groundwise Utilities search has been undertaken. Utilities have been identified primarily at the eastern and western site boundaries. The impact of utilities on the development will be reported separately.

9.10 Geo-environmental Issues

Further ground investigation will be required in order to discharge planning conditions related to contaminated land and in particular to:

- Refine the conceptual site model (CSM) following the UK approach to assessing contaminated land;
- Provide data to assess the level of risk associated with plausible pollutant linkages identified in the CSM; and
- Develop an appropriate remediation strategy.

The data obtained from the investigation and subsequent assessments will assist in the pricing of the ground works and building substructure. The investigation should also be designed to provide data to assess concrete classification and pipeline material specification for costing purposes.

10 Geotechnical and Geo-environmental Risk Register

Table 11 below is a summary of the geotechnical and geo-environmental project and commercial risks identified at the desk study phase. Health and Safety (CDM 2015) risks will be presented separately. This register should be considered as a live document and at key stages of the project, this register should be reviewed and updated as more information becomes available.

Table 11: Geotechnical and Geo-environmental risks identified at the desk study phase

Hazards	Relevant Site Features	Significance	Recommendation
Geotechnical			
Stratigraphy	Made Ground variable with several large obstructions. Two distinct regions/ages of fill identified that will require characterisation. Variable depth to rockhead.	High	Site specific ground investigation (GI) should be carried out to ascertain likely ground conditions including stratigraphy and design soil parameters. Characterisation to be carried out within areas of two different ages of fill.
Groundwater	Perched groundwater is likely to be found within the made ground. Sandstone bedrock is a principal aquifer, with an unknown groundwater level. Tidal Influence expected to be minimal on this side of the dock based on earlier work.	High	Site specific ground investigation (GI) should be carried out to include monitoring of both the superficial and bedrock geology. Further monitoring during a tidal cycle to be undertaken during the GI work to confirm earlier studies.
Aggressive Ground	Made Ground may contain sulphates or chlorides that may potentially be damaging to concrete.	Medium	Site specific ground investigation (GI) should be carried out to include chemical testing of the made ground and be considered in design. Site classification to be undertaken following this to allow appropriate materials specification.
Ground Contamination			
Site wide contamination	Made Ground and/or groundwater may contain a range of contaminants that may be potentially harmful to human health and controlled waters.	High	Site specific ground investigation (GI) should be carried out to include chemical testing of the Made Ground and groundwater. Appropriate

Hazards	Relevant Site Features	Significance	Recommendation
			human health and controlled waters risk assessments should be undertaken and remediation undertaken where necessary.
Ground Gas	Soils beneath the site may have the potential to generate ground gases which could pose an asphyxiation or explosive risk	High	Site specific ground investigation (GI) should be carried out to include gas monitoring to allow a gas risk assessment to be undertaken. Appropriate gas protection measures should be incorporated into the building design according to the outcomes of the risk assessment.
Heritage			
River Wall	There is the potential for the existing river wall to be present to the east of the dock wall discussed below. The extent to which this historical feature remains in-situ is subject to uncertainty.	Medium	A programme of ground investigation (GI) is proposed which will include measures to investigate the location, geometry and condition of the wall. This will need to be as carried out under Archaeological supervision.
Dock Wall	It is thought that the dock wall runs north-south central to the site. This has been identified as an archaeological feature and therefore specialist guidance and approvals are needed prior to any works related to the dock wall.	Medium/ Low	A programme of ground investigation (GI) is proposed which will include measures to investigate the location, geometry and condition of the wall. This will need to be as carried out under Archaeological supervision.
Boundary Wall	The Grade II Listed Boundary Wall and associated gates has been identified as an archaeological/heritage feature and specialist guidance and approvals are needed prior to any works related to this wall. Archive data indicated that footings related to the overhead railway remain.	Medium	Site specific ground investigation (GI) should be carried out to investigate the location and geometry of the footings and to survey them for records. This should be carried out under Archaeological supervision.
Surface features – cobbles/setts	Damage to surface heritage features need to be minimised or avoided where practical.	Medium	Excavations should be carried out under

Hazards	Relevant Site Features	Significance	Recommendation
and railway tracks			Archaeological supervision.
Below Ground Features			
River Wall	There is the potential for the existing river wall to be present to the east of the dock wall discussed below. The extent to which this historical feature remains in-situ is subject to uncertainty.	Medium/ Low	Input from archaeologists is required to determine the heritage value of the river wall based on the findings of ground investigation. Consideration of the need for an appropriate exclusion zone in design.
Dock Wall	It is thought that the dock wall runs north-south central to the site. This has been identified as an archaeological feature and therefore specialist guidance and approvals are needed prior to any works related to the dock wall.	High	Input from archaeologists is required to determine the heritage value of the dock wall based on the findings of ground investigation. Consideration of an appropriate exclusion zone in design. The adjacent Malmaison building adopted a 6.5m zone around this feature.
Voids behind Dock Wall	There is the potential for voids behind the existing dock wall. Such features have been identified as part of historical investigations in the area although at the western side of the dock.	Low	Site specific ground investigation (GI) should be carried out to identify the potential of voids.
Ground Anchors	Ground anchors associated with the sheet pile wall are known to be present. Back plates are thought to be located on the line of the western site boundary.	Low	These anchors support the retaining wall to Princes Dock and disturbance of the anchor plates should be avoided during the proposed development. Excavation to the front of these should be strictly prohibited and excavations close to the back or sides should be very carefully controlled.
Concrete Stanchions	From information obtained from archive data, supplemented by the findings of the 2016 Stage I GI, concrete stanchions have been left in-situ. These stanchions pose a potential obstruction for piling.	Medium	Consideration as part of the foundation design and clashes should be considered. It may be necessary to consider an extra allowance for relocating piles and

Hazards	Relevant Site Features	Significance	Recommendation
			redesign of pile caps in such locations.
Utilities	Archive information suggests there are a number of utilities that may be affected by or pose an obstruction to the proposed development.	Medium	Groundwise Utilities Survey to be reviewed in light of proposed development to assess impacts. Ensure the information is shared with all parties involved in the development.
Unexploded Ordnance (UXO)	During WWII, around 2,500 bombs were dropped on Liverpool, leading to considerable damage across the city. No complete bomb census mapping for Liverpool has survived, however there is a potential for UXO to be present on the site.	High	An Explosive Ordnance Desktop Threat Assessment concluded that there was a medium to high risk of UXO at the site. UXO risk mitigation measures have been recommended, e.g. Explosive Ordnance Safety and Awareness briefings to site personnel, and provision of Explosive Ordnance Disposal (EOD) Engineer on site to support intrusive works.

11 Conclusions and Further Work

Ove Arup and Partners (Arup) have been commissioned by Moda Living to undertake a geotechnical and geo-environmental desk study for the proposed development of 'Princes Reach, Liverpool'. An overview of the findings and recommendations for further work is as follows:

11.1 Site History

Historical plans show that the site was once offshore and has undergone significant development throughout its history. The construction of Princes Dock started in 1811, and was formally open on 19 July 1821. The boundary wall construction started in July 1813 to ensure security for the dock. The 1851 County Series map shows the completed Princes Dock and the 1894 map shows sheds along the dock wall, largely covering the site. An overhead railway line is present to the eastern boundary of the site, along the perimeter of Bath Street. Additional railway lines were since constructed between the new sheds and the overhead railway line (these rail lines are still evident on the site).

In 1928-29 reinforced concrete stagings were constructed over the full length of the eastern dock wall. In the early 1980's and 1990's the shed/buildings were demolished and the site has since operated as a surface car park.

In the 1990's extensive reclamation works were carried out within the dock. As part of this work the concrete staging was demolished, although the supporting vertical stanchions were left in place. The area was subsequently backfilled and a new anchored sheet pile retaining wall constructed, to retain the new access road. The fill beneath the access road was also improved by vibrocompaction techniques.

The site is currently hardstanding with areas of cobbles and tarmac, and is currently derelict although it has previously been used as car parking.

11.2 Ground Conditions

The ground conditions have been assessed based on publically available information and Arup's prior experience to working in the area. A limited initial phase of intrusive investigation has also been undertaken [17]. Table 12 presents the assumed ground model for the site. Figure 15 presents an indicative East-West cross section through the site based on available information. The assumptions in this assessment will need to be validated by carrying out further phases of ground investigation specific to the needs of the proposed development.

Table 12: Proposed ground model for Princes Reach site.

Stratum	Dockside Thickness (m)	Landside Thickness (m)
Made Ground	12.00	6.00
Sherwood Sandstone	>90.00	>90.00

The Sherwood Sandstone is a primary aquifer. It is possible that perched groundwater will be present within the Made Ground, above any zones of less permeable fills.

To the west of the former dock wall, Made Ground is generally loose brown, gravelly sand containing some demolition debris, including large concrete blocks up to 1m³ in size. To the east of the former dock wall, Made Ground has been shown to be sandstone fill, most likely deposited during the construction of the dock. It is possible that obstructions in the Made Ground may act as constraints both to any ground investigation works or to construction activities such as piling.

Groundwater is anticipated to be at a depth that approximately equates to dock water level and not expected to be influenced by tidal changes. From historical groundwater monitoring nearby groundwater levels are likely to be between 2.3 and 4.5m below existing ground level.

11.3 Below Ground Constraints

The historical river wall has been identified at two locations to the east of the dock wall. Although the location and condition of the river wall was not determined at all locations within the site, from the remains encountered it appears likely that the masonry from the river wall may have been robbed out to some extent during the construction of Princes Dock.

The original dock wall has been identified as being present running north to south, almost centrally through the site. This dock wall is an archaeological asset and therefore specialist guidance and approvals are needed prior to any works related to the dock wall.

The Grade II Listed boundary wall between the site and Bath Street has been identified as a heritage asset and therefore specialist guidance and approvals are needed prior to any works related to the wall. It is understood from archive information that footings associated with the wall still remain. These may pose a potential obstruction to the proposed development, depending on the masterplan aspirations in this area.

It is recommended that the location and geometry of the walls and footings be investigated further during subsequent stages of intrusive investigation that are proposed. The heritage value of these historic features is to be determined by archaeological specialists and their recommendations will need to be considered as part of the strategy for the proposed development of the site.

It has been established that concrete stanchions that originally supported the concrete staging, have been left in-situ. These stanchions pose a potential obstruction for piling and therefore as part of the foundation design, clashes should be considered. It may be necessary to consider an extra allowance for relocating piles and redesign of pile caps in such locations.

11.4 Archaeology

Several heritage assets have been identified on the site, and an Archaeological Consultant has been appointed as part of the project and their specialist advice should be sought and considered at every stage of the project.

Archaeology should be considered as part of the design of subsequent ground investigation and the scope of works should endeavour to minimise the impact on surface heritage assets where possible.

11.5 Preliminary Foundation Strategy

Due to the high loads imposed by the proposed development and the variable nature of the Made Ground, it is not considered that shallow spread foundations would be appropriate for the development. It is envisaged that large diameter (750mm to 1200mm) conventional bored cast in situ piles, socketed in to the underlying sandstone, will provide the most appropriate foundation strategy.

The use of driven piles or bored CFA piles are likely to be unsuitable for the expected ground conditions and loading requirements.

Subject to obstructions and the required exclusion zones, the use of a piled raft may be more appropriate rather than discrete pile caps.

An appropriate exclusion zone around the existing river wall and dock wall should be considered for foundation design.

It is possible that ground gas generated from the Made Ground will be encountered and consideration of a gas membrane and passive sub slab void former should be considered. A site specific ground investigation will assess the likelihood of this requirement.

11.6 Unexploded Ordnance

A preliminary Unexploded Ordnance Risk Assessment was obtained from BACTEC. This assessment was based on data held for the Liverpool area and recommended that a full Explosive Ordnance Desktop Study was undertaken for the site.

A full Explosive Ordnance Desktop Study was undertaken by Dynasafe BACTEC [16], which concluded that there was a medium to high risk of UXO at the site. It was recommended that UXO risk mitigation measures were implemented for any proposed intrusive works, including Explosive Ordnance Safety and Awareness briefings to site personnel, and the provision of an Explosive Ordnance Disposal Engineer on site to support intrusive works.

11.7 Further Work

Based on the risks identified in this report, the following further work is recommended:

- Further site specific ground investigation as discussed below;
- A specific Archaeological Desk Based Assessment and Investigation carried out by an appointed Archaeological Contractor;
- Continued liaison with an Archaeological Consultant following confirmation of the foundation strategy; and
- Review and reporting on the Groundwise Utilities Survey.

11.7.1 Site Specific Ground Investigation

At the time of writing, a preliminary Stage 1 investigation has been completed [17], however further investigation will be required to address the issues identified in the Conceptual Site Model and other issues identified in this report. The full recommended scope of intrusive investigation works (including the Stage I works that have already been completed) comprises the following:

Geotechnical

- 4No. Cable percussion boreholes to approximately 15m depth (to competent rock) with Rotary core follow on to a further depth of 10m below competent rock depth;
- 6No. Hand dug pits to approximately 1.2m depth to prove depth of eastern boundary wall and to investigate the location of utilities in the west;
- A series of machine excavated pits to approximately 4.5m depth to assess ground conditions and to expose, log and accurately survey the existing dock wall.
- 3No. Window Sample Holes to approximately 6m depth;
- 4No. Dynamic probes to a depth of approximately 10m to investigate the geometry and extent of the dock wall;
- In-situ SPT testing in boreholes;
- Soil sampling for geotechnical laboratory testing;
- Geotechnical laboratory testing of soil and rock samples to include:
    - Index testing (Atterberg limits, moisture content, densities)
    - Particle Grading
    - UCS
    - Point Load Index testing
    - Determination of stiffness parameters
- Chemical testing of soil and water samples to include;
    - pH and sulphate
- Installation of combined gas and groundwater standpipes in boreholes with monitoring of water levels and ground gas over a minimum of six rounds. Monitoring should be undertaken at different point in the tidal cycle to allow for assessment of the effects of tides on groundwater levels and the ground gas regime;

- Site re-visits for groundwater and gas readings.

Geo-Environmental

- Laboratory testing of soil samples collected from geotechnical boreholes;
- Post-fieldwork groundwater and gas monitoring over a minimum period of six weeks;
- Allowance of 4No. Groundwater samples collected from installed standpipes for chemical analysis.

An Archaeological Contractor will be appointed directly by the Client and will be responsible for providing an Archaeological Watching Brief during the geotechnical works as well as supervising specific geotechnical pits, cleaning and recording heritage assets, overseeing hand dug pits and completing final permanent reinstatement of areas of Archaeological Importance.

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